A COMPARISON OF THE CAMBRIAN AND ORDOVICIAN RIPPLE-MARKS FOUND AT OTTAWA, CANADA[1]

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Introduction.—We are told by an eminent geographer that "the most important part of the geological labors of the ocean is hidden from our eyes."[2] The evident truth of this observation affords a sufficient reason for making a careful record of every fact which may help to throw light on the processes of sedimentation. Ripple-marks on sandstones and sandy shales are among the most familiar of the characters with which marine sediments have been impressed, but we have yet much to learn concerning them. These features when fully understood will tell us much more of the local physical conditions under which they were formed than we are at present able to infer from them. It still remains for future research to determine whether a law can be deduced which will connect the length and height of waves with the width of the ripple-marks resulting from the simultaneous water oscillation. Among the present needs in connection with the effort to acquire a more fundamental knowledge of ripple-mark phenomena appear to be recorded data on (1) the different types of ripple-marks to be met with in a given set of beds where the factors of depth and texture of sediment are uniform, (2) characteristics which distinguish ripple-marks associated with particular kinds of sediment from those found in other sediments.

The observations in this paper are recorded with this twofold object in mind. The Cambrian and Ordovician sediments both show well-developed ripple-marks in horizons which are exposed in the Ottawa district. The Cambrian ripple-marks which will be described occur in sandstone, while those in the Ordovician are impressed upon limestone.

[1] Published with the permission of the Director of the Geological Survey of Canada.

[2] Elisée Reclus, *A New Physical Geography*, Vol. II (1890), "The Ocean," p. 103.

Cambrian ripple-marks.—Cambrian sandstone is extensively exposed in a flat-topped hill 12 miles west of Ottawa, just south of the intersection of the Canadian Northern and Grand Trunk railways. The rock is a hard, white to buffish-gray, moderately coarse sandstone. It is thin-bedded, lying in strata 2–10 inches thick. Some of the strata are beautifully ripple-marked.[1] All of the ripple-marked beds and those associated with them appear to be quite barren of fossils, although a *Lingulepis acuminata* Con. occurs abundantly a little lower in the section along the railroad. Two

FIG. 1.—Ripple-marks in Cambrian sandstone. The large slab shows the symmetrical type with low ridges and broad flat troughs; the asymmetrical type is represented by the small slab at the right of the picture.

distinct types of ripple-marks occur in the highest beds exposed on the hilltop. Both of these are shown in Fig. 1. The type seen in the smaller slab on the right of the picture is better shown in Fig. 2. The ripple-marks shown on the large slab are symmetrical, the two sides of the ripple ridge having the same slope or curvature. Those seen on the smaller slab and in Fig. 2 are asymmetrical, the slope of the ridges on one side being much steeper than that of the ridges on the other side. The symmetrical ripple-marks show some features in which they differ from those usually met with in sandstones.

[1] I am indebted to Mr. L. D. Burling for directing my attention to these ripple-marks.

Instead of the usual rounded or angular trough between the crests, the ripple ridges rise from interspaces which are almost or quite flat. The gently rounded parallel ridges are separated by flat interspaces generally one and one-half to two times their width. Traces of a diminutive ridge in the middle of the flat-bottomed trough may sometimes be noted. This type of ripple-mark is comparable in its essential features with, though not precisely like, a form of ripple-mark which I have seen developed in Lake Deschênes near Ottawa. A photograph of these sand ripple-marks made from a cast of a mold taken under water at Lake Deschênes is here reproduced in Fig. 3. Comparison of the two figures shows broad, nearly flat troughs in each separating the comparatively narrow rounded ridges. In the Lake Deschênes specimens the miniature secondary ripple-marks are more clearly developed than in the sandstone ripple-marks. The lake ripple-marks were formed under natural conditions in water 6 inches deep and were under observation during and after their development for a period of three days. They are the product of water oscillation resulting from a very gentle on-shore breeze. This breeze and the accompanying wavelets were not strong enough to produce the asymmetrical type of ripple-mark with steep leeward and gentle windward slopes which results from more vigorous movement of the water and leaves a record of the direction of the movement of

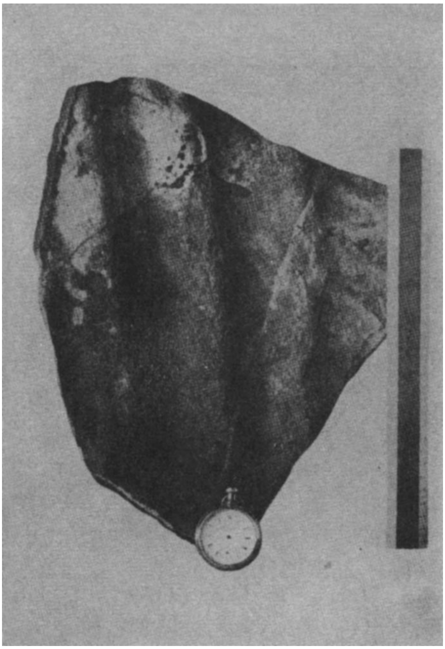

FIG. 2.—Cambrian sandstone slab showing asymmetrical type of ripple-mark.

the waves or currents concerned in its production. The similarity in type of the Cambrian and Lake Deschênes ripple-marks shown in Figs. 1 and 2 suggests the inference that the Cambrian impressions probably represent the work of winds and waves of a very gentle character.

In beds which lie within a very few inches of the symmetrical ripple-marks which have been described occur the asymmetrical ripple-mark type shown in Fig. 2. The ripple-marks in the specimen shown in Fig. 2 have a width from crest to crest of 3 inches and a trough depth of one-fourth inch. Their lee and stoss slopes are, respectively, 9°–15° and 20°. These ripple-marks trend about S. 35 E. and present their steep sides toward the northeast. Ripple-marks of this type represent either a wind or water current moving in a northeasterly direction. An interesting feature of these ripple-marks is the presence of a second set of much finer and less distinct ripple-marks which show sometimes clearly but generally faintly on the stoss slopes of the prominent ripple-marks. These secondary ripple-marks cross the others at an angle of about 45°. If they are the product of wind rather than current action, they indicate a shift of wind of nearly a quadrant from the position which it must have maintained during the development of the larger ripple-marks. At the time these Cambrian sands were deposited the nearest shore of the Cambrian sea lay five or six miles to the northeast if we may judge from the close proximity and relative elevation of the archean rocks in the Laurentian mountains on the opposite side of the Ottawa valley. The wind or current direction indicated by both of these sets of ripple-marks therefore appears to indicate a general on-shore direction.

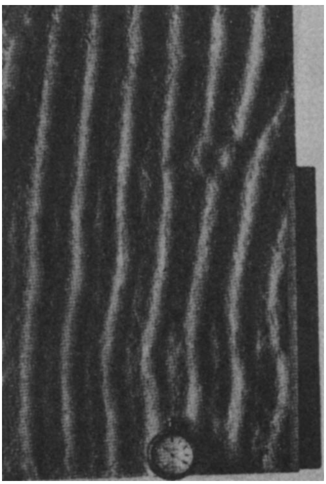

FIG. 3.—Cast from mold of sand ripple-marks taken under water at Aylmer, Quebec. Compare with Fig. 1.

Trenton limestone ripple-marks.—The extensive quarry in the Trenton limestone at the cement mill one-half mile northwest of Hull, Quebec, exposes a section with a vertical thickness of nearly 100 feet. Three or four horizons in this section show, in the vertical walls of the quarry face, contacts between adjacent beds which are very suggestive of ripple-marks of large dimensions. The imperfect exposures of the lower of these horizons leaves room for some question as to their true nature but it appears clear that the uppermost is an example of ripple-marks. Only the uppermost of these horizons, which is admirably exposed for study through the stripping of the stone to this level over an area of considerable extent, will be considered here.[1] This bed lies 10–15 feet below the top of the quarry in the part of the section called by Dr. Percy Raymond[2] the crinoid beds.

The limestone here is a dark-gray rock lying in strata usually 6 inches to a foot in thickness. The regular horizontal contact of these strata gives way at the horizon under discussion to a billowy trough and crest contact. This is much less regular in profile than the profile of the ordinary ripple-mark as seen in most sandstones. The somewhat irregularly rounded summit of the ridges and their variable width might suggest on brief examination an unconformity; their parallelism and the identity of the fauna on both sides of this horizon, however, render this explanation untenable. The ridges trend approximately east and west and their axes are from 2 to 3 feet apart. No sharp crests are to be seen. All of them, as shown in the photographs (Figs. 4 and 5), are rounded or somewhat depressed on top. The troughs have an average depth of about 6 inches below the crest and frequently coalesce, thereby producing many short ridges. An interesting feature connected with these ripple-marks is the occurrence on them at some points of numerous crinoid stems some of which have the heads attached as shown in Fig. 6. These are often two feet or more in length and indicate by their presence that the crinoids lived on this part of the sea bottom shortly after the formation of the ripple-ridges in water

[1] These were brought to my notice by Mr. W. A. Johnson.

[2] "Excursions in Neighborhood of Montreal and Ottawa," *Guide Book No. 3* (1913), p. 143.

which was sufficiently quiet not to break up the stems into the small sections usually found in limestone. Above the ripple-marks 6 or 8 inches, however, there is equally clear evidence of current action

FIG. 4.—General view of ripple-marks in Trenton limestone at cement quarry, Hull, Quebec.

FIG. 5.—Close view of ripple-marks in quarry at Hull, Quebec

at a later period having been involved in the distribution of the materials comprising some of the beds. At this level a band of cross-bedded limestone a few inches in thickness occurs with layers inclined at about 27°. The material comprising these current-

built beds consists largely of small fragments of crinoid stems and other fossils.

Comparison of limestone and sandstone ripple-marks.—These Trenton limestone ripple-marks show a striking contrast with those of the Cambrian sandstone which have been described, in the matter of size. Instead of an amplitude of 2 or 3 inches which characterizes the Cambrian ripple-marks, these have a width of 2 or 3 feet from crest to crest. This discrepancy in size is of interest because it exists between the great majority of the examples of limestone ripple-marks and sandstone ripple-marks which have come under my notice. I have observed very few cases where the amplitude of ripple-marks in sandstone exceeded a few inches.[1] On the other hand, six of the eight photographs in my collection illustrating limestone ripple-marks, which represent as many different geological horizons and widely separated localities, show an amplitude of more than one foot. The data given in geological literature relative to limestone ripple-marks are often too incomplete to furnish data on the amplitude, but where given the amplitude is likely to be represented by a figure much larger than those which usually represent the amplitude of sandstone ripple-marks.

The earliest description of limestone ripple-marks with which I am acquainted relates to ripple-marks of large amplitude. This occurs in Dr. John Lock's description[2] of the "Blue Limestone" (Ordovician) of southwestern Ohio. Under the head of "Waved Strata," he described a stratum in which "the upper side is fluted out in long troughs 2–3 feet wide and about 2 or 3 inches deep, the edge or ridge between them being generally sharp. . . . . These waves are not local, but may be traced in the same stratum over tracts of many miles."[3]

Dr. August Foerste states[4] that "wave-marks (ripple-marks) occur in Ohio, Indiana, and Kentucky, in abundance in the Lower Eden, Upper Richmond, and upper Brassfield limestones. They

[1] Mr. G. K. Gilbert has recorded one exceptional case in the Medina sandstone in which the amplitude is reported to be several feet (*Bull. Geol. Soc. Am.*, X, 135).

[2] *Geol. Surv. of Ohio* (1838), p. 246, Pl. 6.

[3] Lock expressed the belief that these were not ripple-marks because "all geologists will agree that the blue limestone has been formed far below the reach of ripples."

[4] Letter to the writer.

occur in great numbers, but not so abundant, also in the Middle Eden. In Kentucky they are common also locally in the Mount Hope bed, at the base of the Maysville. They occur often near the middle of the Arnheim and at various intervals in the Lower and Middle Richmond in the three states mentioned." Dr. Foerste has recorded[1] a considerable number of observations on the limestone ripple-marks in the Ordovician and Silurian formations of these three states. Most of those which he observed appear to be of large size, those seen at one locality having crests 49 inches apart which rise $3\frac{1}{2}$ inches above the troughs.[2] Foerste remarks that "their unusual size will, however, attract attention even from one familiar with the work of the sea." Moore and Allen[3] have published photographs and descriptions of Upper Ordovician (Richmond) limestone ripple-marks with an average amplitude of 2.63 feet which occur in eastern Indiana.

In New York state, Miller[4] has described ripple-marks in the Trenton limestone of Lewis county which measure 24–56 inches from crest to crest with troughs 4–7 inches deep. At another locality in the same state, Professor Cushing[5] has described ripple-marks in the Trenton limestone with an amplitude of 9–15 inches and a depth of 1–3 inches. Cushing remarks concerning these that "they are considerably broader than the usual ripple-marks in sandstones." This observation, it may be noted, tends to confirm the opinion already expressed by me that sandstone ripple-marks have generally a comparatively small amplitude.

But few references to ripple-marks on Silurian limestones have come under my notice. Two of these which relate to New York and Ohio localities may be cited. East of Lockport, New York, Kindle and Taylor[6] report ripple-marks in the uppermost member

[1] "On Clinton Conglomerates and Wave-Marks in Ohio and Kentucky," *Jour. Geol.* III (1895); 1–10 (reprint). "The Richmond Group along the Western Side of the Cincinnati Anticline in Indiana and Kentucky," *Am. Geol.*, XXXI (1903), 333–61.

[2] *Jour. Geol.*, III, 37.

[3] *Proc. Ind. Acad. Sci. 1901* (1902), pp. 216–18, Pls. 1–3.

[4] *Bull. N.Y. State Mus. No. 135* (1910), p. 36.

[5] *Bull. N.Y. State Mus. Nat. Hist. No. 77* (1905), p. 34.

[6] *Folio U.S.G.S. No. 190* (1913), p. 7.

of the Clinton limestone which have crests 18–30 inches apart with troughs 2–4 inches deep. Foerste[1] mentions ripple-marks in the Springfield dolomite, west of Peebles, Ohio, one-fourth mile. Professor Prosser[2] states that the ripple-marks at this locality occur in two beds. "In the lower layer the crests of the ripples are 22 inches apart and the trough 4 inches deep. In the upper layer the crests are 45 inches apart and the troughs 4½ inches deep."

In the Devonian, I am acquainted with but three examples[3] of ripple-marked limestones. Each of these shows an amplitude of 2 feet or more.

The only notice of Mesozoic limestone ripple-marks[4] which has come to my attention records the occurrence of ripple-marks in limestone of Jurassic age in Utah with an amplitude of 6–12 inches.

The examples cited above from the literature of limestone ripple-marks plainly indicate the large size usually attained by ripple-marks in pure limestone. It must be noted, however, that ripple-marks of small size also sometimes occur in limestone. A photograph of ripple-marks on a dolomitic limestone with a smaller amplitude than the sandstone ripple-marks reproduced in this paper has recently been published;[5] and Miller[6] mentions Ordovician examples with an amplitude of 1–2 inches. Foerste[7] has observed that large and small limestone ripple-marks in the Ordovician of the Ohio valley are seldom associated but confined to distinct horizons. One must therefore conclude that the generally larger size of limestone as compared with sandstone ripple-marks results from some factor other than the different physical characteristics of the two kinds of rock. It seems probable that the explanation is to be sought in the fact that limestones are generally formed somewhat farther from the shore and in deeper water than sandstones. The different average amplitude of sandstone and limestone

[1] *Jour. Cin. Soc. Nat. Hist.*, XVIII (1896), 167.

[2] Letter to the writer, February 6, 1914.

[3] One of these has been described (*Ottawa Nat.*, XXVI [1912], 1–3, Pl. 7).

[4] G. K. Gilbert, *Science*, III (1884), 375–76.

[5] Kindle and Taylor, *Folio U.S.G.S. No. 190* (1913), Pl. 25.

[6] *Bull. N.Y. State Mus. No. 135* (1910), p. 36.

[7] Letter to the writer.

ripple-marks may be related to the relative average depths at which limestone and sandstone sediments accumulate. In other words, the usual large amplitude of limestone ripple-marks may be a function related to the depth of the water in which they are formed. If we apply this as a working hypothesis to the case under consideration, we must conclude that the ripple-marks in the Trenton limestone near Ottawa were formed under water of considerably greater depth than those in the Cambrian sandstone. The presence of long

FIG. 6.—View showing profusion of crinoidal remains found on the surface of some of the ripple-marks in cement quarry at Hull. Photograph by L. D. Burling.

crinoid stems upon the limestone ripple-marks is significant in connection with the question of the depth of the water under which they were formed. They were developed during an interval when a luxuriant crinoid fauna flourished in this part of the Trenton sea. All of the members of this order which live in the present seas are found, with a very few exceptions, in comparatively deep water. The living stalked crinoids are found chiefly at depths of more than 200 fathoms; a few extend into 140 fathoms and a very limited number into 58 fathoms, while one or two species are known in still shallower water. Geologists are accustomed to infer the

former existence of shallow seas where corals are the dominant fossils, and it seems an equally safe deduction to infer a sea of considerable depth where stalked crinoids comprise the dominant element in the fossil fauna as they do in the ripple-mark horizon under consideration. The occurrence on the ripple-marks of numerous crinoids in which the head remains joined to nearly complete stems (Fig. 6) affords direct evidence that they lived in water of sufficient depth to be seldom disturbed by wave action. The well-known fragile character of the union of the individual segments of a crinoid column and of the head and column could not be expected to survive the bottom disturbance of ordinary wave action. It is probable that the ripple-marks on which the crinoids rest are the result of storm waves of unusual size whose oscillations penetrated to a depth not affected by ordinary waves. It appears from these considerations that both the physical and the faunal evidence suggest for the ripple-marks in the Trenton limestone an origin in water of greater depth than the ripple-marks in the Cambrian limestone.